

Investigation of Model Sensitivities and Model Errors with Relation to Data Assimilation Systems

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LONG-TERM GOALS

To investigate basic predictability issues related to model sensitivities to uncertainties in the initial and boundary conditions; how these sensitivities are dependent on different model dynamics, different data types and data distribution; how their assessment can lead to the evaluation of model errors as intrinsic component of the data assimilation method used.

OBJECTIVES

- a) To assess the dynamical mechanisms that ultimately limit the predictability of a flow system.
- b) To assess uncertainty in models by evaluating estimates of model error covariances from the assimilation method used.

APPROACH

Dr. Mark Buehner was a Postdoctoral Associate at MIT under the present grant during the period July 1, 2000–June 30, 2001. During this period two research projects were completed.

1) Reduced-Rank Kalman Filters applied to an Idealized Model of the Wind-Driven Ocean Circulation.

The goal of this study is to evaluate a specific type of reduced-rank Kalman filter for application to realistic ocean models. Data assimilation experiments were performed using an idealized nonlinear model of the wind-driven ocean circulation. Separate configurations of the model were employed that exhibit either a quasi-periodic behavior on the decadal time scale or a statistically stationary behavior accompanied by a high level of mesoscale eddy activity. The model consists of about 10^4 prognostic variables with observations of the model state taken at 30 locations concentrated in the region of highest variability near the western boundary.

The assimilation scheme is an approximation to the extended Kalman filter in which the error covariances and corrections to the forecasts are only calculated in a reduced dimension subspace spanned by a small number of empirical orthogonal functions (EOFs). The filter was implemented using both temporally evolving and asymptotically stationary error covariances. Additionally, for the quasi-periodic regime, the model state space was partitioned according to the distinct flow regimes exhibited by the model and the asymptotically stationary error covariances calculated for each regime. The performance of these reduced-rank approaches is compared with the more traditional approach of

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using stationary error covariances with a simple prescribed functional form. The results show that the reduced-rank Kalman filter is able to reduce the error in all assimilation experiments and consistently performs better than using prescribed error covariances. Also, the performance of the filter with stationary error covariances is surprisingly similar to the much more computationally expensive filter with flow-dependent covariances. The importance of specifying appropriate model and observation error covariances and the difficulties related to using stationary basis functions are also discussed.

2) The Tropical Atlantic Circulation estimated from Altimetry Data with a Reduced-Rank Stationary Kalman Filter.

A reduced-rank stationary Kalman filter is applied to a realistic model of the tropical Atlantic ocean. The goal is to estimate the sub-surface circulation and thermal structure for studies of the circulation pathways in the Atlantic subtropical and tropical gyres by assimilating TOPEX/POSEIDON sea surface height (SSH) data.

The model is a reduced gravity, primitive equation GCM of the upper ocean with a variable-depth oceanic mixed layer and a domain covering the Atlantic ocean between 30°N and 30°S. Wind stress and heat flux, calculated from wind speed and cloud cover provided by NCEP, are used to force the model at the surface. The assimilation scheme is an approximation to the extended Kalman filter in which the error covariances of the state estimates are only calculated in a reduced-dimension subspace spanned by a small number of EOFs. Results from previous studies concerned with assimilating SSH in the tropical ocean suggest that the cost process of dynamically evolving the error covariances only result in minor improvement to the state estimates. Therefore, to obtain an assimilation procedure, which only requires slightly more computational efforts than simple model integration, the asymptotically stationary error covariances are used.

Assimilation of simulated SSH data in twin experiments demonstrates the ability of the method to successfully constrain the circulation and subsurface thermal structure (figure 1). Assimilation of actual TOPEX/POSEIDON altimetry data resulted in a 23.6% reduction in the rms. Misfit with observed SSH relative to pure model integration (figure 2). Also, the agreement between the power spectra of the observed and model SSH is significantly improved by the assimilation. Evaluation of the impact on the subsurface fields is more difficult due to a lack of independent measurements. However, changes in the thermocline structure appear reasonable and the correlation between the observed SSH and the depth of the model thermocline are improved by the assimilation (figure 3).

On April 1, 2001, Dr. Xiaoyun Zhang joined MIT under the present contract. He has started working on the construction of an ensemble Kalman filter for the idealized wind-driven model of which is at point 1. A major first objective of the research will be to analyze in a systematic manner the sensitivity of the assimilations to the size of the ensemble.

PRESENTATIONS

Buehner, M. and P. Malanotte-Rizzoli, A low-rank stationary Kalman filter applied to a QG reduced gravity model, AGU special session on the DRI, S. Francisco, December 2000.

P. Malanotte-Rizzoli, Balanced initializations and data assimilations in ocean GCMs, European Geophysical Society XXVI general Assembly, Nice, France, March 2001, Invited paper.

M. Buehner, P. Malanotte-Rizzoli, T. Inui, and A.J. Busalacchi, The tropical Atlantic circulation estimated from altimetry data with a reduced-rank stationary Kalman filter, CLIVAR workshop, Paris, September 2001.

PUBLICATIONS

Mahadevan, A, J. Lu, S.P. Meacham, and P. Malanotte-Rizzoli, "The predictability of large scale wind-driven flows", to appear in the special issue of *Nonlinear Processes in Geophysics*, L. Smith and Z. Toth, eds.

M. Buehner and P. Malanotte-Rizzoli, 2001, "Reduced-rank Kalman filters applied to an idealized model of the wind-driven ocean circulation" under revision for the *J. Geophys. Res.*

M. Buehner, P. Malanotte-Rizzoli, T. Inui, and A.J. Busalacchi, 2001, "The tropical Atlantic ocean circulation estimated from altimetry data with a reduced-rank stationary Kalman filter", submitted to *J. Geophys. Res.*

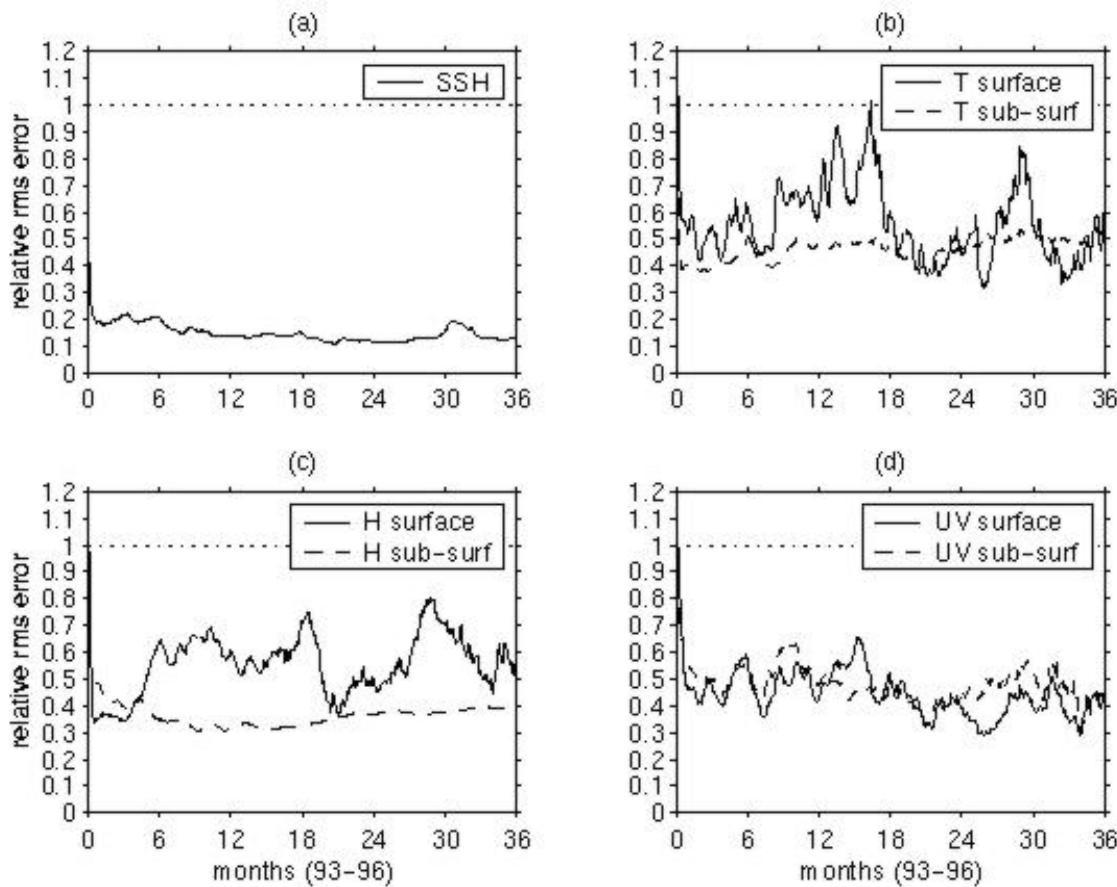


Figure 1. Relative rms error from the three-year identical twin assimilation experiment. The rms error from the assimilation run is normalized relative to the run without assimilation. (a) Error in the estimated SSH, (b) Error in the estimated temperature, (c) error in the estimated layer thickness, (d) error in the zonal (U) and meridional (V) components of velocity. Panels (b)-(d) show the relative error for the surface layer and the remaining sub-surface layers separately.

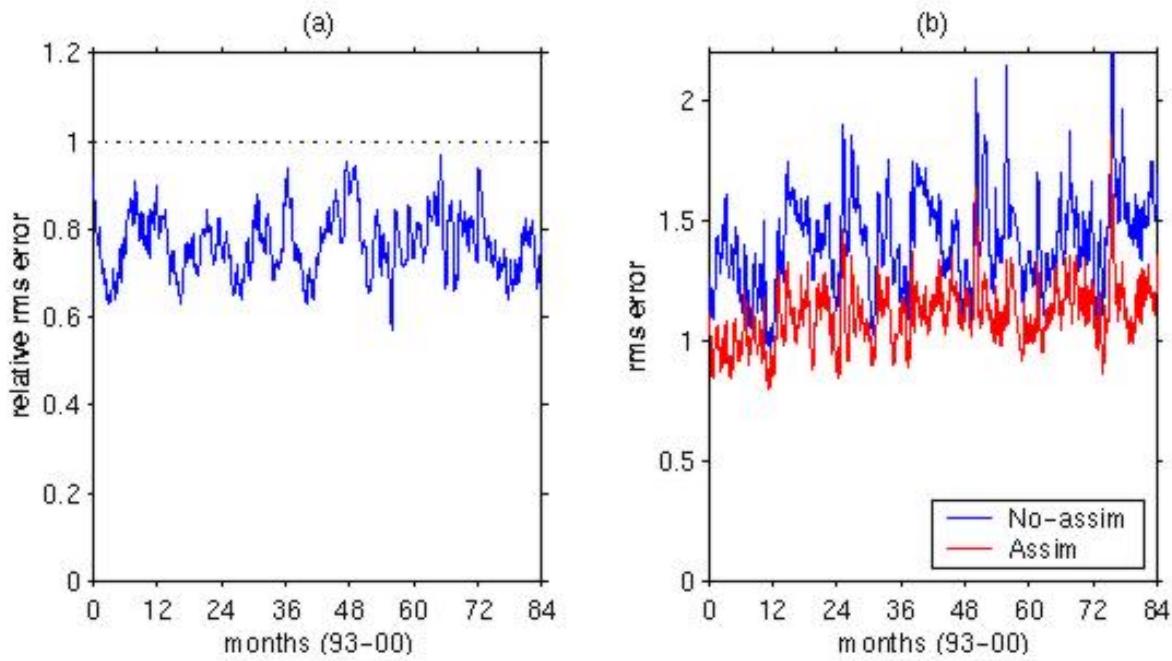


Figure 2. The rms error from the TOPEX/POSEIDON altimetry assimilation experiment measured relative to the observations. The relative rms error after normalizing by the error from the “false” ocean run is shown in (a) and the no-dimensional rms error for the “false” ocean run and for the 3 day forecasts and analyses from the assimilation run are shown in (b).

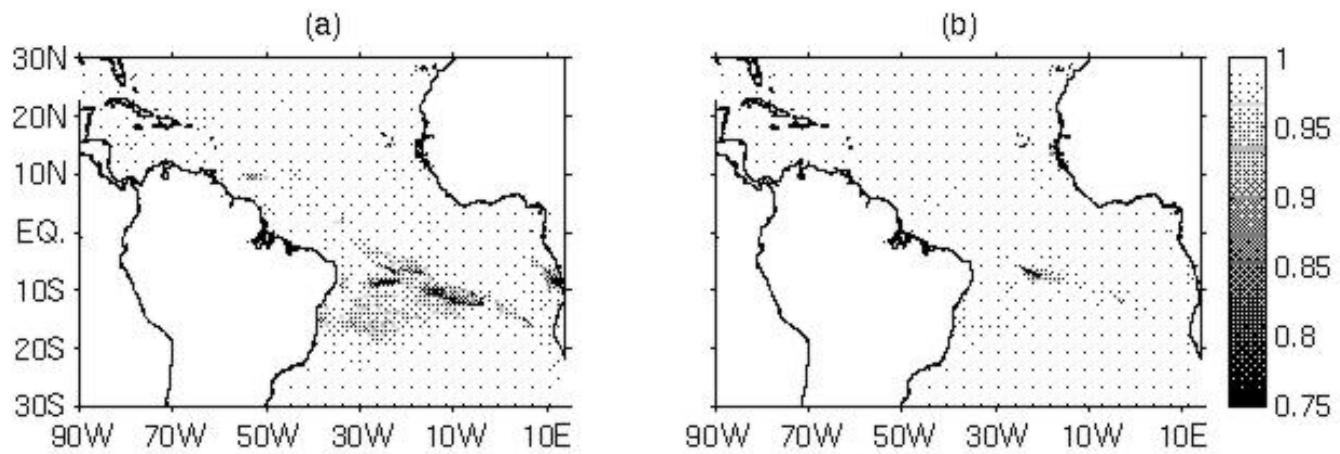


Figure 3. The correlation of the depth of the 14 degree isotherm with the SSH from the non-assimilation run and from the TOPEX assimilation run.